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RELATION BETWEEN THE STABILITY CHARACTERISTICS AND THE CONTROLLABILITY OF GERMAN AIRPLANES

By Walter Hübner

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I n t r o d u c t i o n

The expression "flight characteristics" denotes the behavior of an airplane under the action of deflected controls and external disturbances, while the expression "flight performances" refers to its climbing, speed, take-off and landing qualities. Speed and climbing performances are exclusively unaccelerated phenomena within the range of normal flight. Flight characteristics comprise a great variety of accelerated and unaccelerated phenomena, even including those which lie outside the range of normal flight. Flight performances are determined as simple lift and speed performances by the flying weight, the aerodynamic excellence of the wings, the engine power and the propeller efficiency. Flight characteristics depend on the location of the C.G., on the profile characteristics, on the size and shape of the control surfaces and on the mass distribution. While it is comparatively easy to calculate and measure perform-

*"Stabilitätseigenschaften und Steuerbarkeit der deutschen Landflugzeuge," a lecture before the W. G. L., February 8, 1929. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, October 28, 1929, pp. 521-528.

ances, both the theoretical and the experimental determination of flight characteristics are difficult. In general, the performances can be estimated and measured with an accuracy of nearly 10%, while the characteristics, except in a few special cases, can be determined only by experience.

The difficulty of calculating the characteristics is not the only reason, however, which accounts for the development of performances over characteristics. Until quite recently, uncertainty had prevailed as to what characteristics are required and as to how they are affected by the structural features of an airplane, due to the fact that the solution of these problems had been the task of the pilot or the common task of the theorist and pilot. Pilots have an aversion to theoretical considerations. Moreover, their vocabulary is so peculiar that they cannot be easily understood by formal theorists. The latter, thus left to themselves, lack practical experience which, in this particular field, cannot always be replaced by any amount of theoretical knowledge.

Under these conditions, even long after the war, attention was chiefly concentrated upon improving airplane performances. Characteristics were left to depend on chance. When they happened to be good, it was simply attributed to good luck. Yet the utility of an airplane type depended largely on its characteristics, especially during the war, although no adequate reason could be given as to why one type was better or more popular

than another. At that time stress was laid only on "banking maneuverability" which belongs to the performance group, since it depends chiefly on the values which determine climbing ability.

The chief purpose of the German aeronautical industry after the war was to attain great economy. Yet there can be no economy without safety, and an airplane is safe only when it is easily controllable in any position and therefore has good flight characteristics. The problem of flight characteristics is a question of safety. Hence the development of good flight characteristics is of vital importance to civil aviation.

It is difficult to say when German manufacturers made the first conscious effort toward improving the characteristics of their airplanes. The development became general in 1926 when, by government order, the test department required specific flight characteristics. The present state of development is briefly summarized below.

Relation between the Stability Characteristics and the Controllability of German Airplanes

The sum of all the conditions which determine the behavior of an airplane under the action of deflected controls and external disturbances, depends on the four factors: stability, controllability, maneuverability, and spinning characteristics. By "stability" is meant the behavior of an airplane removed from its condition of equilibrium. "Controllability" refers to the action

of the controls, i.e., the turning moment produced by a given deflection of a control surface, or the resulting angular velocity about the corresponding airplane axis and the force required to produce or maintain this deflection of the control surface. "Maneuverability" is the ability of an airplane to make controlled motions in space. "Spinning characteristics" cover the behavior of an airplane in autorotation.

The following discussion is confined to the stability and controllability of German landplanes. We will first consider the behavior of an airplane about its lateral axis, which is approximately parallel to the direction of the wing spars; then its behavior about the normal axis; and lastly, its stability and controllability with respect to the longitudinal or fuselage axis.

<u>a) Stability and controllability about the lateral axis</u>.- Stability about the lateral axis is also called longitudinal stability. Controllability about this axis is achieved by means of the horizontal tail surfaces. In unaccelerated flight with the gas throttle in a fixed position, a specific angle of attack and hence a definite dynamic pressure correspond to each deflection of the elevator. Figure 1 shows this dynamic pressure or, if a given air density is assumed, the speed of equilibrium as a function of the elevator deflection for an airplane of the Udet-Flamingo type. The figure shows that the control stick must be pulled for low speeds and pushed for high speeds. The

speed can be changed simply by an adequate pull or push on the control stick. This results in the desired change in the angle of attack, which is maintained without any further effort on the part of the pilot. Thus only a single control motion is required in each case to change the speed. Such an airplane is stable with fixed elevator.

The conditions are quite different with an unstable airplane. Figure 2 shows that a push on the control stick of an unstable airplane corresponds to a low speed, and a pull corresponds to a high speed. In order to change the speed (e.g., from 125 to 140 km/h - 77.7 to 87 mi./hr.) the control stick must first be pushed, in order to reduce the angle of attack, and then pulled back again beyond the point of elevator deflection corresponding to a speed of 125 km/h. The control stick must therefore be moved twice, in order to change the speed of an unstable airplane. Flying with an unstable airplane requires more work and attention than flying with a stable airplane.

Besides, unstable airplanes are not so safe as stable ones. The range of action of each control is limited. When a control surface is deflected beyond a certain amount, its effect is not further increased. Under the action of the controls or of a squall, an unstable airplane easily reaches such small or large angles of attack that the action of the controls is inadequate to keep the airplane in equilibrium and to restore it to its original attitude. Under these conditions the airplane is gener-

ally lost. If the control over the airplane is lost at small angles of attack, it will usually go into a steep inverted dive and remain in that condition. If the control is lost at a large angle of attack, the airplane may go into a spin. For the sake of safety, any instability with fixed elevator should be completely eliminated.

The control stick of a stable airplane is operated logically, i.e., a pull corresponds to a low speed, and a push corresponds to a high speed. The pilot does not rely, however, entirely on the deflection of the controls or on the position of the control stick, just as he does not rely on the indications of his instruments, except when visibility is lacking. He is guided by the pressure on the stick, which he feels, and by the magnitude and direction of the control forces. The ideal case is when the pilot feels no control force in the most important state, that of cruising speed, but feels a nose-heavy control force in pulling (i.e., at low speed) and a tail-heavy force in pushing. The variation of the control forces should therefore be consistent.

This variation is illustrated by Figure 3, which represents a control-force measurement on a Heinkel HD 32 airplane. With such stability characteristics, the pilot, guided only by feeling, without the aid of his eyes, can determine the attitude of his airplane by the magnitude and direction of the control forces. This diagram of the control forces is that of an air-

plane which is stable with floating elevator.

Except for a few special cases, stability with the elevator fixed is a necessary condition to insure stability with the elevator floating. This condition, however, is not sufficient. An airplane can be stable with the elevator fixed and unstable with it floating. Then the control forces vary as shown in Figure 4. According to this figure the airplane is tail-heavier at low speeds than at high speeds. Yet the control forces can be zero at a given speed, but their variation is not consistent. Such an airplane is not absolutely reliable.

If an airplane is stable with floating elevator or (according to the present-day justifiable assumption of small control friction) with released control stick, it must also have other good qualities. With released control stick the airplane returns automatically to its condition of equilibrium, which is usually that of cruising flight. Its safety does not depend on the pilot's continuous attention. In bad visibility when the pilot lacks points of comparison for his position in flight, he can recover his original attitude by simply releasing the controls. Even failure of the controls does not entail the danger of a crash. Stability with released controls is therefore at the present time the best attainable result in so far as piloting and safety are concerned. German airplanes built after 1927 are stable with released controls. This stability exists, even when the airplane is balanced poorly, i.e., when the C.G. is as

far aft as possible.

The term "stability" is often confounded with the term "trim." The latter merely indicates that, at a given speed, an airplane ceases to be in equilibrium with the controls released. Hence the trim is determined by the speed at which the control force is zero. If, in the case of stability with floating elevator, the control force becomes zero at a lower speed than the cruising speed, the airplane is then tail-heavy in cruising flight. If the control force becomes zero at a speed exceeding the cruising speed, the airplane is then nose-heavy in cruising flight.

Of course equilibrium, or a zero control force, can also be attained by an unstable airplane. The airplane is then in a state of unstable equilibrium. The trim can then be changed by altering the stabilizer setting. Changing the stabilizer setting does not, however, improve the stability.

Up to this point it has been assumed that, for the same speed, the position of the gas throttle (that is, the engine power) remains constant. Any change in the position of the throttle changes the velocity and direction of the slipstream. At different positions of the throttle the air strikes the tail surfaces at different impact pressures and in different directions. Hence the trim changes, so that the state of equilibrium is shifted from one impact pressure to another, or that, in order to maintain the same speed, another elevator deflection

and another control force become necessary. Figure 5 illustrates a control-force measurement on a Heinkel HD 32 airplane with wide-open throttle and also with idling engine. The figure shows that equilibrium is reached (i.e., the control force becomes zero) at approximately 93 km/h (58 mi./hr.) at full throttle, while a speed of about 190 km/h (118 mi./hr.) must be reached with idling engine. A control force of approximately 5.5 kg (12.1 lb.) must be exerted in order to maintain an idling speed of 93 km/h. There is a great difference between the trim at full throttle and when idling. The Heinkel HD 32 airplane is a rather old type. This difference is much smaller on modern airplanes.

Experience shows that an airplane of normal construction grows nose-heavy with throttled engine. Hence it is in equilibrium at a higher speed than with an engine developing more power. An airplane with released controls zooms when the throttle is opened and goes into a glide when the throttle is partially closed. This quality is very useful, since it enables piloting an airplane by means of the throttle. Thus an airplane with broken controls can be flown by means of the throttle and even landed with little or no damage, as has already happened on several occasions. The difference in trim, due to the propeller slipstream, must not, however, be so great that, when the engine is throttled, the airplane will attain such a high equilibrium velocity or grow so nose-heavy, as to lose the advantages of stability with released controls. German airplanes are so built

that they fly horizontally with the throttle in the position of cruising flight and with released controls. With completely throttled engine they go into gliding flight with an increase in speed of approximately 10 to 20%.

The best way to achieve these stability characteristics is to locate the C.G. of the airplane relatively far forward. The C.G. of airplanes built during the last few years lies from 24 to 35% of the mean wing chord aft of the leading edge, while the C.G. of airplanes built from 1920 to 1926 lay at 40 to 50% of the wing chord. Formerly most airplane designers endeavored to locate the C.G. so that the wing and the tail plane moments would be zero in cruising flight. Thus the C.G. lay far aft, especially in the case of the highly cambered wing sections frequently used in Germany. This practice was based on the assumption that, in the absence of any elevator moment in cruising flight, the change in the trim from the action of the propeller slipstream would be small. This assumption, however, was not confirmed by experience. In all cases yet observed, when the C.G. was located farther aft, the change in the trim was found to be increased.

Good stability characteristics with the C.G. located far aft can only be acquired by great length of the fuselage and excessive size of the control surfaces, which greatly increase the weight and drag. The after location of the C.G. often resulted in spins. Experience shows that only airplanes with a C.G. locat-

ed not more than 33% of the wing chord from the leading edge can be surely recovered from spins. During the past year wing sections have been used, the C.P. of which travels but little or not at all. With such wing sections it is relatively easy to meet the stability requirements. Owing to the use of balanced elevators on certain airplanes, the stability with floating elevator is nearly as great as with fixed elevator. Longitudinal stability calculations usually agree quite well with practical results, except for high-wing airplanes whose wings are secured directly to the top of the fuselage.

At the present time it is absolutely impossible to calculate the effect of the propeller slipstream. The direction of flow and the dynamic pressure in the propeller slipstream cannot be determined with the accuracy required for the calculation of the slipstream effect. The flow in the propeller slipstream is turbulent as shown in Figure 6. The distribution of the pressure and the direction of flow in the propeller slipstream depend on the wing arrangement, on the shape of the fuselage, on the flying speed, and on the modulus, pitch, diameter, and shape of the propeller.

The dynamic longitudinal stability of present-day aircraft has presented no difficulties at the speeds thus far attained.* In exceptional cases, tail plane vibrations have caused longitudinal vibrations of increasing amplitude. Even with released con-

*In the meanwhile a few cases of dynamic longitudinal instability with floating elevator have been observed.

trols, the longitudinal vibrations of German airplanes are usually much damped. The order of magnitude of the periods of vibration is 30 to 45 seconds. Figure 7 represents such a damped vibration, which quickly fades away after a purposely very strong disturbance.

With the stabilizer in the cruising-flight position and the engine throttled down to idling speed, the elevator effect of any airplane type must be adequate to attain the angle of attack of maximum lift even with the C.G. in its farthest possible forward position. This requirement follows from the necessity, in low flight, of immediate readiness for forced landings without preliminary adjustment of the stabilizer. The requirements resulting from the above condition are usually exceeded by the elevator effect of stunting airplanes. It can be said that the highest degree of control efficiency is sought for the latter.

A strong elevator effect is disproportionate to the strength of the wing. In reply to this objection, it can be claimed that a good pilot never utilizes the full elevator effect at high speeds (Fig. 8). Controls designed for low speeds are oversized at high speeds. In order to avoid accidents due to these conditions, it would be useless to increase the strength of the wing, but highly desirable to give pilots adequate training.

The direction and variation of the control forces were considered above as functions of the flying speed. Speaking of the absolute magnitude of the control forces, the latter should under

no condition and in no attitude of flight exceed the power which the pilot is capable of exerting for a long time without fatigue. A force of 10 kg (22 lb.) applied to the elevator control is severely felt by the pilot. This should be the limit of the admissible control force in unaccelerated flight and should not be exceeded, if the airplane is to be kept in equilibrium at large angles of attack with the stabilizer in cruising-flight position and the engine throttled. The difficulty of regulating the control forces increases with increasing dimensions and speed of the airplanes. In most cases the problem can be solved only with the help of balancing surfaces. By reducing the chord only, elevators of great aspect ratio would be obtained. With such elevators there is danger that their maximum lift may be exceeded. The use of balancing surfaces is therefore becoming more general. Figures 9, 10, and 11 show the three main types of external, internal, and auxiliary balances.

The use of external and internal balances permits of easily controlling the weight moments of the control surfaces. For the purpose of avoiding vibrations, the C.G. of the elevator is located as near as possible to its axis of rotation. For this purpose balancing weights are used in the balancing surfaces. It must be taken into consideration that in shifting the C.G. of the elevator forward, the longitudinal stability with floating elevator is reduced. Besides, the trim of the airplane changes with the weight moment of the elevator.

b) Stability and controllability about the vertical axis.- Stability about the vertical axis which depends on the vertical tail surfaces is also called directional stability. All German airplanes possess directional stability even with released rudder control. As soon as this control is released the airplane returns automatically to its position of equilibrium. Owing to the asymmetry of the propeller slipstream, this position of equilibrium depends greatly on the position of the throttle. It is easy, however, to cause this state of equilibrium to correspond to straightaway flight at cruising speed. With wide-open throttle and released rudder control, the airplane goes into a flat turn in one direction, but with partially closed throttle it goes into a flat turn in the opposite direction. This property which cannot be determined by calculation, is obtained by placing the tail fin sufficiently aft of the C.G. of the airplane and by giving it suitable dimensions and shape. In some cases the stabilizing effect is produced by a balanced rudder.

The shape of the tail fin is now different from that of war airplanes. Though the triangular shape prevailed during the war, the trend is now toward the trapezoidal shape. Moreover, the aspect ratio of the vertical tail surfaces has been increased. In certain cases stability about the vertical axis is produced by the fuselage alone. The cross section of the fuselage is then rectangular, the longer sides of the rectangle being vertical. The tail fin is never adjustable in flight. To offset

the asymmetry of the propeller slipstream, the central line of the fin section often forms an acute angle with the longitudinal axis of the airplane. Even when there is no propeller slipstream and only a small forward speed the rudder action suffices to produce side-slipping. Of course the airplane also has satisfactory banking characteristics.

An airplane with an engine located on each side of the axis of symmetry must have a very efficient rudder. If one of the side engines fails, the rudder must not only enable the pilot to keep the airplane on a straight course, but also to overcome the thrust moment of the still running engine about the vertical axis and turn the airplane in the direction of the running engine. This requirement has been fulfilled, without changing the setting of the tail fin, even by twin-engine airplanes the rudder action of which is not supported by the propeller slipstream. The fin and rudder forces are controlled by external, internal and auxiliary balances in the same way as the horizontal tail surfaces.

Particular atress is laid on adequate rudder efficiency at large angles of attack. Not only is the rudder effect reduced by the smallness of the impact pressure in this flight attitude, but the fin and rudder are also shielded by the horizontal tail surfaces. Yet good rudder efficiency is particularly important at large angles of attack. A rudder, which is still efficient at large angles of attack, can prevent a stalled airplane from

winging over and going into a spin. Hence the rudder can stop an incipient spin.*

For the rudder action to be extended to large angles of attack, at least a part of its area must be withdrawn from the shielding effect of the horizontal tail surfaces. Hence the rudder must extend below the horizontal tail surfaces. For this purpose the elevator is divided. The area of the rudder portion below the horizontal tail surfaces is usually increased by increasing the length of its chord (Fig. 12). Rudders of this shape are also more efficient on the ground.

c) Stability and controllability about the longitudinal axis.- Stability about the longitudinal axis is usually called "lateral stability." There is no such direct stability about this axis, however, that any departure from the position of equilibrium engenders restoring moments. Such moments are set up indirectly only, when a bank causes side-slipping and hence a change in the direction of attack. When the wing is inclined to the horizon, the airplane begins to side-slip. This motion produces moments about the longitudinal axis which restore the airplane to its original attitude. These moments are usually small. They can be increased by setting the wings at a dihedral angle. In this sense, even warped wings and those of the Focke-Wulf

*This experience confirms the theoretical investigations of Von Baranoff. (See 92d D.V.L. Report, "Einige Ergebnisse über den Uebergang eines Flugzeugs ins Trudeln," 1928 Yearbook of the Deutsche Versuchsanstalt für Luftfahrt, p. 205.

type have very good lateral stability. Not all German airplanes possess this indirect lateral stability, which is indispensable for flying in fog. Airplanes can be used for most other purposes, even if they lack lateral stability, since this stability is partly replaced by the damping about the longitudinal axis.

Within the range of normal flight, any rotation about the longitudinal axis causes great damping moments which oppose the rotation. When an airplane rotates about its longitudinal axis, the angle of attack of the portion of the wing moving downward during the rotation increases, while the angle of attack of the upward-moving portion of the wing decreases. Within the range of normal flight any increase in the angle of attack corresponds, however, to an increase in lift. Hence the lift of the downward-moving portion of the wing is increased. Any reduction in the angle of attack corresponds to a decrease in lift, whence the lift of the upward-moving portion of the wing is increased. Parallel moments are set up about both wing portions. They oppose and hence "damp" the original rotation.

The lift increases with increasing angle of attack only within the range of normal flight. Conditions are reversed when the maximum lift is exceeded. Any increase in the angle of attack then corresponds to a reduction in lift and any reduction in the angle of attack corresponds to an increase in lift. In this case the rotations about the longitudinal axis are no longer damped in stalled flight.

Damping moments about the longitudinal axis are strongly positive at high speeds. They decrease with increasing angle of attack and become zero before the minimum speed is reached. If the angle of attack is further increased, the damping moments become negative. Beginning with a certain angle of attack, rotations about the longitudinal axis not only cease to be damped, but are even intensified. Once a rotation is started, it continues, usually with increasing angular velocity. This condition is called autorotation and the resulting motion is called spinning.

The absence of a damping effect about the longitudinal axis, above an angle of attack near that of maximum lift, causes an airplane to have full controllability only within a small range of angles of attack in normal flight. Of course, purposely or not, large angles of attack can be easily reached, but in this stalled condition, the lateral axis of the airplane can be held parallel to the horizon for only a short time at most. Lack of positive damping about the longitudinal axis is the chief defect of present-day aircraft. No practical advantage is now attributed to spinning. It is, on the contrary, being endeavored to make all airplanes spinproof, so as to prevent winging over in case of accidental stalls. Airplanes should therefore be positively damped about the longitudinal axis at all attainable angles of attack.

The need of extending the controllability beyond the angle

of attack of maximum lift increases with the improvement in the aerodynamic excellence of airplanes. Airplanes with good aerodynamic qualities (i.e., with small induced and structural drag) have very small gliding angles at all practical angles of attack in normal flight. They can glide at low speed only along flight paths slightly inclined to the horizon and therefore have to glide a long distance before being able to land. A long time and hence a long flight path, often of several kilometers, are required to slow down from cruising speed to landing speed. Even side-slipping does not enable airplanes with good aerodynamic qualities to land easily on fields of normal size when surrounded by obstacles of some height. It requires great skill to land such an airplane or to bring it to a standstill at a given point. These difficulties exist even at small landing speeds. If such airplanes could be flown without danger at angles of attack greater than the angle of maximum lift, the flight path, in landing, could be more steeply inclined to the horizon without increasing the forward speed. Also the speed could be reduced more quickly and within a shorter distance. In order to level off before touching the ground, the airplane must return to normal flight, since the flight path can be bent upward only by increasing the lift. Otherwise, the airplane would hit the ground at the great falling speed of stalled flight. The landing stresses thus produced could be controlled for only very small wing loadings. Airplanes with good aerodynamic characteristics

will probably require the use of air brakes to supplement the positive damping.

All means of insuring positive damping about the longitudinal axis, and hence safe flight even in the stalled condition, are based on the same principle. The wing tips, which have a decisive influence on the damping, must then exert an increasing lift with an increasing angle of attack, even after the maximum lift of the whole wing is exceeded. Hence the maximum lift of the wing tips should be reached only for angles of attack which are larger than that of the central portion of the wing (Fig. 13). This condition can be fulfilled, for instance, by reducing the angle of incidence of the wing sections near the wing tips, thus warping the wing. Of course the wing camber, and hence the maximum lift of each wing section, should not decrease toward the tips. It is, instead, better to increase the camber toward the wing tips. Also, positive damping in stalled flight would probably be produced by the peculiar aerodynamic shape of the Focke-Wulf wing. In this respect, however, the Focke-Wulf wing has been very little tested. Hitherto, it has been found impossible to stall this wing. A small degree of positive damping can be effected by nozzle-shaped slots between the ailerons and the wing. The maximum lift of the wing portion lying within the range of the ailerons is thus increased. The lift increase of an undeflected aileron, however, is only about 10%.

It is impossible to calculate the aileron effect. Wind-

tunnel measurements, from which the aileron effect during rotations about the longitudinal axis can be determined, have not yet been made in Germany. Hence special tests are usually required for each individual airplane, in order to determine the degree of aileron efficiency required for its particular use. According to American and English tests, the influence of the moment of inertia about the longitudinal axis is small. Also the effect of the wing span is usually overestimated. Many German monoplanes of large span have excellent aileron efficiency. The ratio of the aileron chord to the wing chord varies between 1/3 and 1/7. The best value, with respect to the control forces, seems to depend greatly on the thickness and camber of the wing section within the range of the ailerons. The ratio of half the span to the width varies between 1 and 2/5. Ailerons extending over the whole span produced excessive control forces and their use has therefore been discontinued.

The control forces are also reduced by means of the three above-mentioned balances. It is particularly important to reduce the aileron forces on commercial airplanes. Great stress is laid on balancing the weight moments as a means of avoiding the danger of aileron vibrations. The control effects about the three airplane axes and the control forces of the horizontal and vertical tail surfaces and of the ailerons must be harmonized.

Controllability is also greatly affected by the comfort of

the pilot's seat, by the location of the airplane and engine controls, by the visibility, etc. In all these respects German airplanes have been developed to a high degree of perfection.

III. Present State of German Airplane Development

The above survey is intended to give a general approximate idea of the stability and controllability of German airplanes. It would be impossible to go into details without giving personal estimates of the different types, and this must therefore be avoided. Yet the qualities of the various makes do not differ so much, as the great number of different airplane types built in Germany might lead us to expect. In general, the average stability and controllability about the lateral and vertical axes have reached a very satisfactory state. Difficulties are still encountered as regards the stability and controllability about the longitudinal axis. In Germany the controllability in stalled flight must still be regarded as an unsolved problem.

It is very difficult to compare the characteristics of German airplanes with those of foreign makes, owing to the fact that foreign development is known in Germany only through publications and a very small number of sample airplanes. The airplane characteristics required in America, England, and Germany are very similar, although they were developed independently. The agreement between these requirements and the characteristics actually attained is known only as regards German airplanes.

One of the few foreign airplanes tested in Germany is the De Havilland "Moth." This airplane is very popular in England on account of its characteristics which, however, according to German tests, are no better than those of an average German airplane of the same class.

The qualities of the De Havilland "Moth" with slotted Handley-Page ailerons are also known in Germany. We must admit that the controllability and stability of this type in stalled flight has been equaled by no German airplane. German aeronautic construction is still backward in the control of stalled flight. As regards all other flying qualities, German airplanes are the equal of foreign airplanes.

In judging the present state of German airplane development, it should be remembered that their period of evolution has been a very short one and that a great number of technical and economical difficulties had to be overcome.

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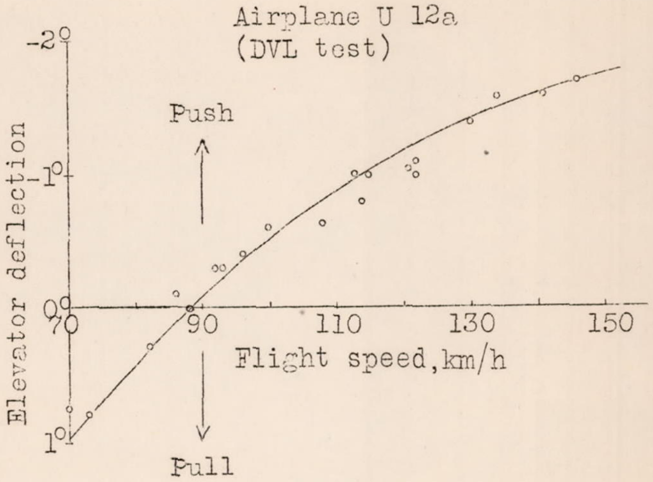


Fig.1 Stability with fixed elevator(elevator deflections in unaccelerated flight).Low speeds correspond to pulls and high speeds to pushes on the control stick.

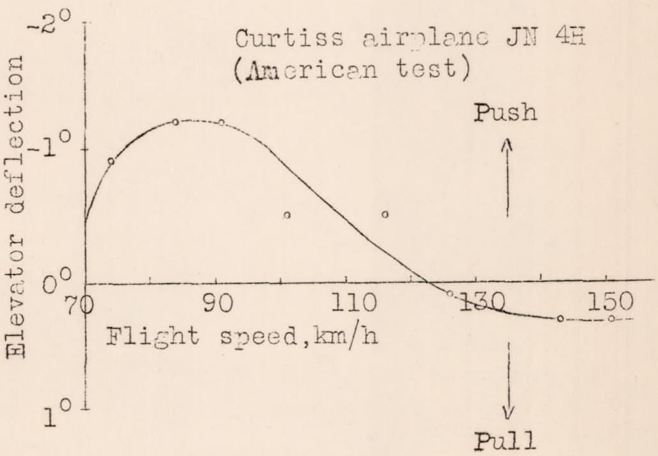


Fig.2 Instability with fixed elevator(elevator deflections in unaccelerated flight.)A push on the control stick corresponds to a low speed and a pull corresponds to a high speed. At speeds of less than 90 km/h ,however,the JN 4 H airplane is stable with fixed elevator.

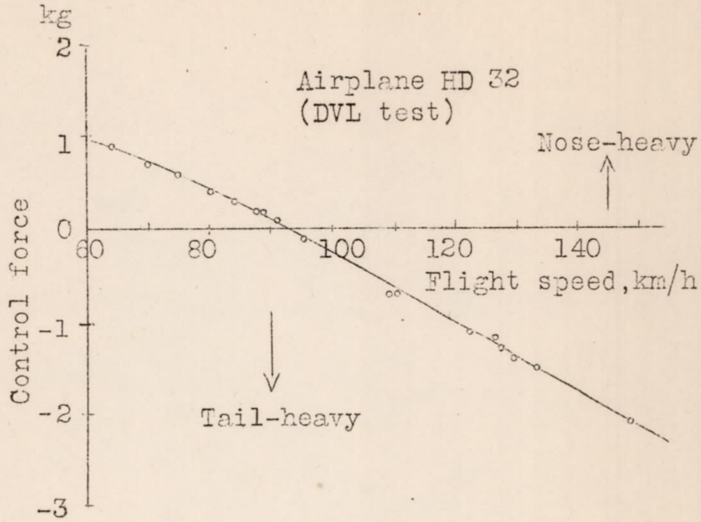


Fig.3 Stability with floating elevator(control forces in unaccelerated flight).Airplane is nose-heavy at low speeds and tail-heavy at high speeds.

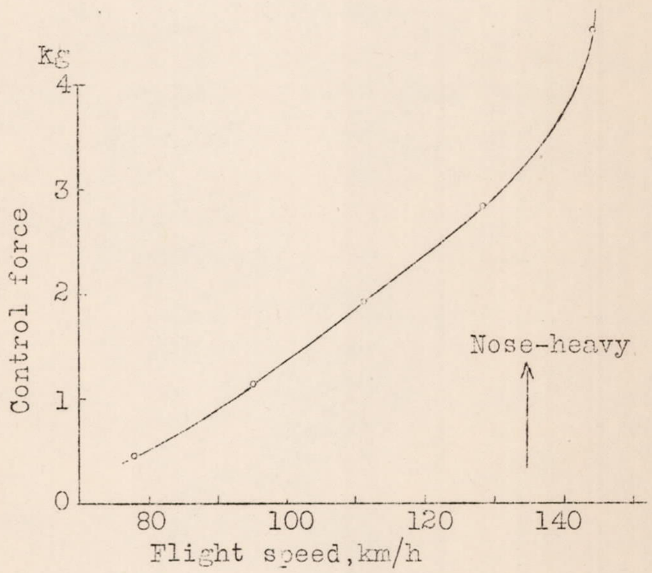


Fig.4 Instability with floating elevator(control forces in unaccelerated flight.)Airplane is tail-heavier at low speeds than at high speeds. Figure shows variation in control force of airplane which is nose-heavy throughout the whole range of normal flight.

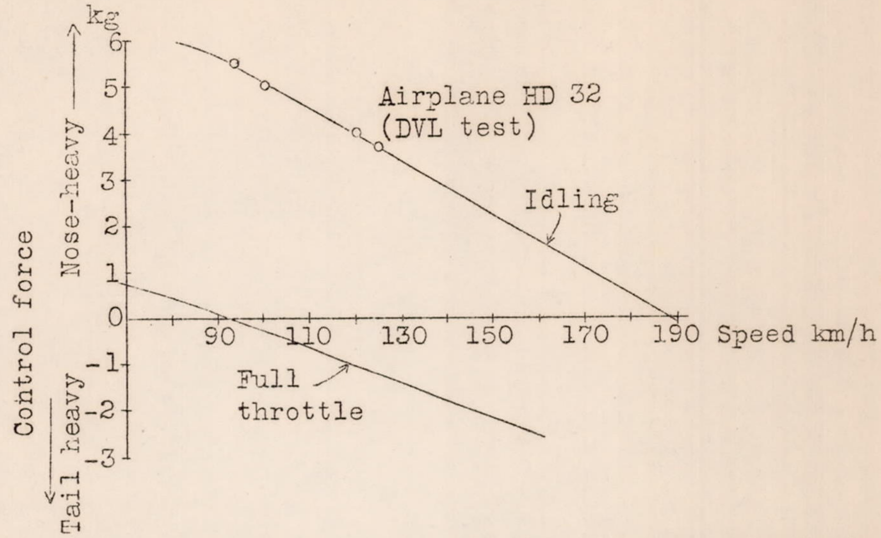
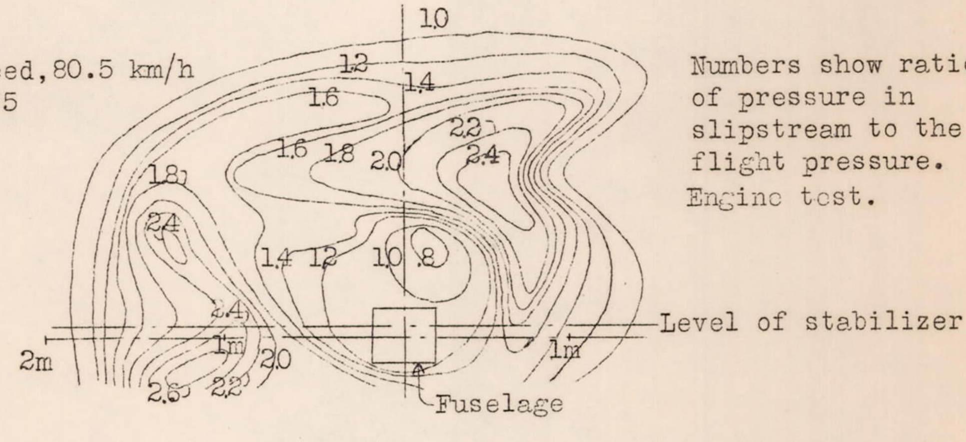


Fig.5 Change of trim under the action of the slipstream.Most airplanes become nose-heavy with throttled engine.Hence equilibrium is reached,with floating elevator and idling engine,at a higher speed than that developed at full throttle.

Flight speed,80.5 km/h
r.p.m.,1495



Numbers show ratio of pressure in slipstream to the flight pressure. Engine test.

Fig.6 Pressure distribution in slipstream.Distribution of pressure in slipstream is unsymmetrical with respect to airplane axes and changes with propeller modulus.

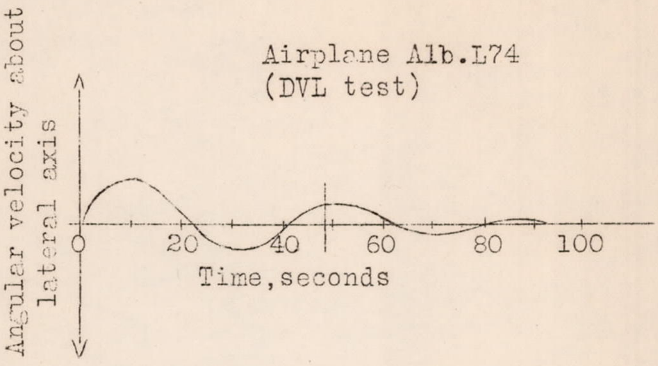


Fig.7 Longitudinal vibrations about lateral axis. Airplane was restored to its position of equilibrium with released controls. Then a great disturbance was created by suddenly throttling the engine and immediately afterwards throwing the throttle wide open. The ensuing oscillations were measured by an angular-velocity recording device.

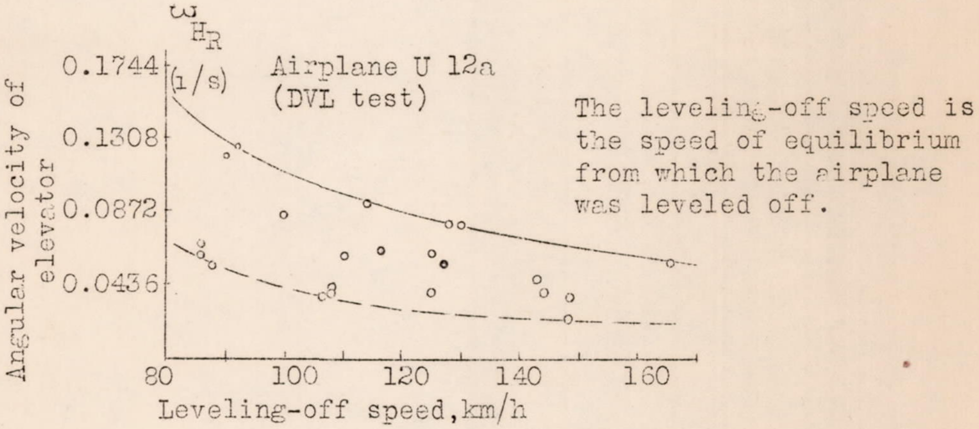
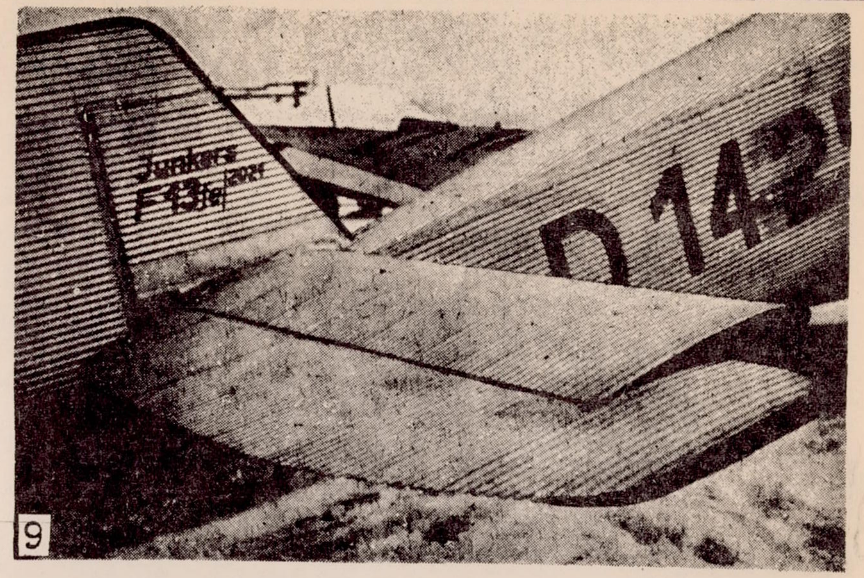


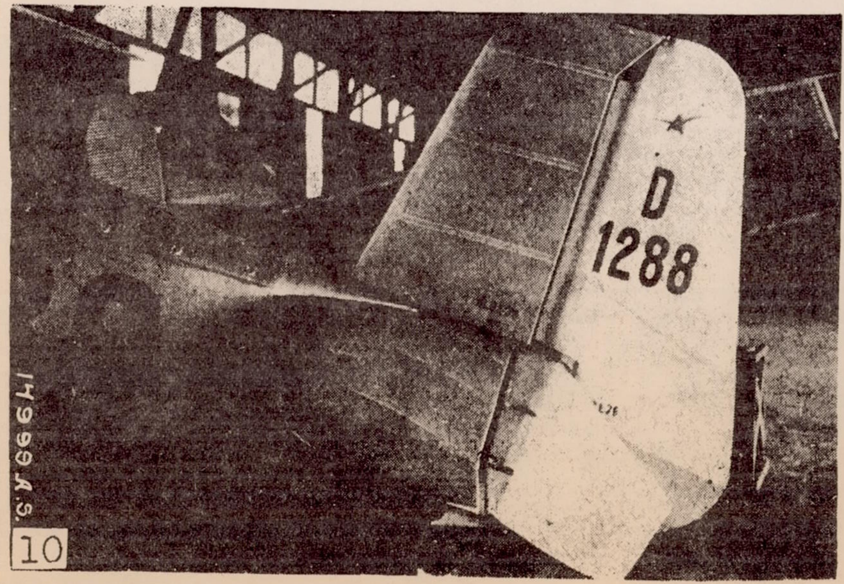
Fig.8 Angular velocity of elevator during recovery from dive. Several pilots were given the task of leveling an airplane off at different dynamic pressures. The angular velocity of the elevator was measured as a function of the dynamic pressure of recovery. Result shows that pilot deflects elevator more slowly in recovering at great dynamic pressures than at small ones.

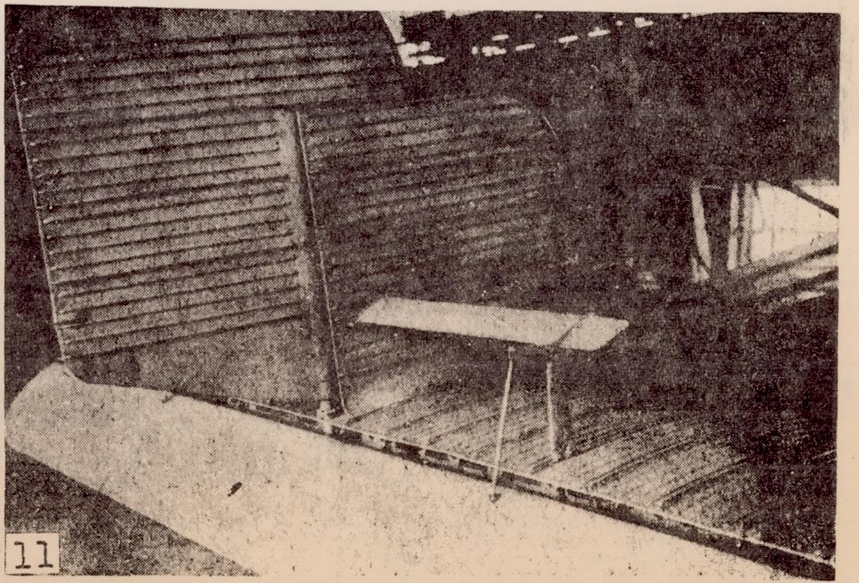
Fig.9 Elevator with balancing surface on a Junkers F.13 f.e.

Fig.10 Internally balanced rudder and elevator on the Albatros L.76 airplane.

Fig.11 Auxiliary balance on elevator of Dornier Merkur airplane. The rudder has a balancing surface







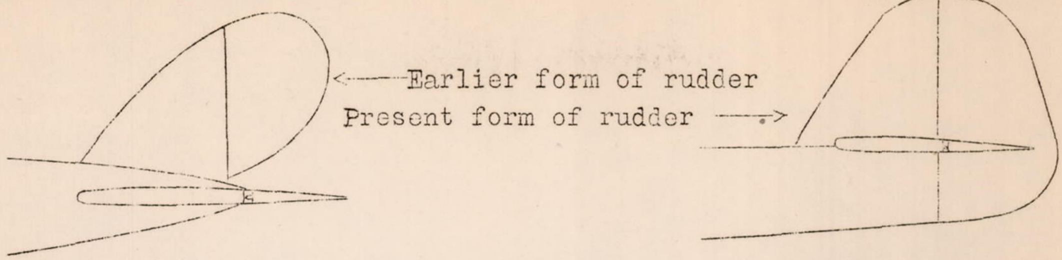


Fig.12 Vertical tail surfaces of old and modern airplanes.On most wartime aircraft the rudder was above the undivided elevator. In order to obtain a good rudder action at large angles of attack,the rudders of nearly all modern airplanes are extended below the divided elevator.

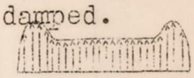
Normal flight
(Wings with and without slotted ailerons behave alike)

The lift distribution is approximately elliptical.

During rotations about the longitudinal axis,the lift of the wing portion moving downward is increased and that of the portion moving upward is decreased.Hence the rotation is damped.

Stalled flight

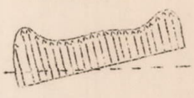
Without slotted ailerons. The lift distribution is roughly elliptical.



With slotted ailerons The lift is greater at the wing tips than in the center.

Stalled flight.

During rotation about the longitudinal axis the lift of the down ward moving wing portion decreases and that of the upward-moving portion increases.The rotation not only is not damped,but is even increased. Autorotation is started.



During rotations about the longitudinal axis,the lift of the downward-moving wing portion increases, while that of the upward-moving portion decreases.Hence rotations about the longitudinal axis are damped.No autorotation takes place.

Fig.13 Damping about the longitudinal axis in normal flight. The figure shows the behavior of normal wings and of wings with tips reaching their maximum lift at angles of attack larger than those of the middle of the wing(e.g.,wings with slotted ailerons)during rotations about the longitudinal axis in normal and in stalled flight.